Shielding Electronics From EMI/RFI

Electromagnetic waves must be effectively shielded from impinging on sensitive circuitry and radiating from or entering electronic enclosures.

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Many electronic circuits are susceptible to electromagnetic radiation (EMR) and must be shielded to ensure proper operation. When EMR is present and affects circuit performance, it is called EMI (electromagnetic interference) and/or RFI (radio frequency interference).

EMI and RFI are basically the same except that EMI encompasses the full spectrum of EMR frequencies, whereas frequencies above approximately 20 kHz are termed RFI. Both terms — EMI and RFI — are now used instead of EMR, even when there may not be any EMR-induced interference to the electronic system. Hence, with respect to shielding, the popular terminology is EMI/RFI shielding rather than EMR shielding.

Another term used is EMC (electromagnetic compatibility). This means that the electronic equipment has been designed to be EMI-compatible with other electronic equipment and will not cause EMI or be susceptible to EMI. EMC testing is a requirement for many electronic systems.

RFI is descriptive of high-frequency, high-impedance radiated electromagnetic waves dominated by an electric field as the major wave component. The gap from DC (direct current) to 20-25 kHz is the area of low-frequency, low-impedance where a magnetic field dominates the EMI wave. Therefore, the two major concerns relating to shielding against the effects of EMI are RFI shielding and magnetic shielding.

The causes of EMI

High-frequency digital circuits are a primary cause of EMI emissions in the RFI range. Signal clocks and high-speed logic devices are regarded as highly RFI-offensive in computer systems. Other major causes of RFI are radio circuits and microwave circuitry. This radiated energy, if not properly shielded, can affect the operation of adjacent circuits, other circuits throughout the electronic system or radiate from the cabinet to affect the circuitry in an adjacent electronics cabinet.

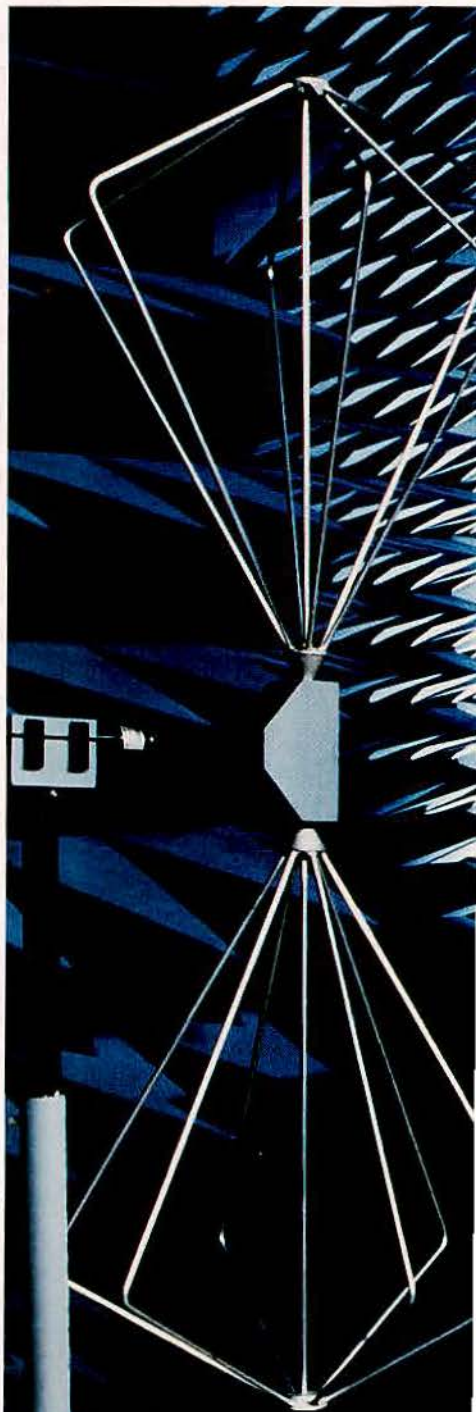
Although the majority of shielding is applied to limit RFI, magnetic shielding is also often required to optimize system performance. Low-impedance EMI is generated by transformers, motors, solenoids, permanent magnets or electromagnets and other current-operated devices that produce an external magnetic field. If of sufficient strength, this field will affect other components by inducing electrical currents. An external magnetic field will also distort the image on a CRT display.

RFI shielding requires materials having high conductivity to reflect and absorb the incident RF wave, whereas magnetic shielding materials must be highly permeable (magnetic) to absorb and provide a controlled path for the magnetic lines of force. Materials with low permeability such as aluminum and copper do not adequately shield magnetic fields.

Magnetic shielding

Magnetic shielding is commonly in the form of rigid sheet stock or metal foil made from ferromagnetic material such as nickel-iron. The foil or sheet can be formed to fit over the components to be shielded, either at the source of the field or over those components sensitive to the field.

However, shielding the source of the magnetic field means that the shielding will be required to attenuate a stronger field because of the field's proximity. It is therefore common practice to shield the sensitive compo-



Performed in an anechoic chamber to eliminate ambient RF, a senior technician prescans a computer for FCC Part 15J testing. The prescanning isolates suspected radiated emissions, facilitating subsequent open-field testing. The small loop antenna is used to identify emission sources, typically cables, CRT leakage, floppy disk slots and air vents. (Instrument Specialties)

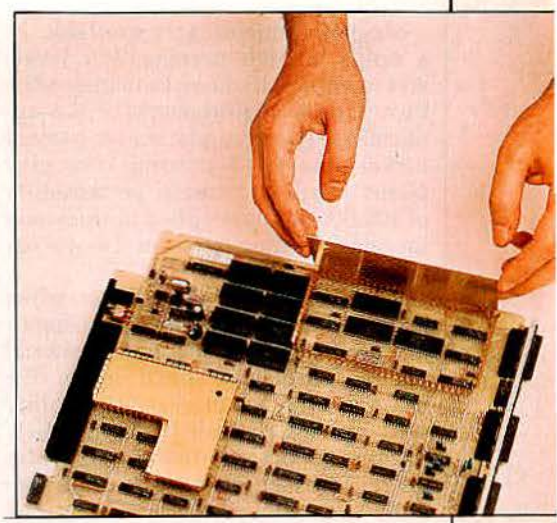


Figure 1. Individual devices on a printed circuit board *can be shielded by an EMI "fence" soldered to the board's ground plane. A cover may be added. (Instrument Specialties)*

nents. The metal shield conducts the magnetic flux around the component and prevents the field from impinging on the component.

Because both the magnetic field and metal shield are of low impedance, most of the energy is absorbed by the shield rather than reflected (see sidebar discussion).

Magnetic shielding is effective until the shielding material reaches its saturation level and cannot conduct additional flux. The excess flux will then penetrate the shield. The shielding material's permeability, saturation level and thickness are the major factors in its ability to attenuate the magnetic field.

Attenuation *(g)* is the ratio of the field intensity outside the shield (the magnetic field source) to the field intensity inside the shield at the component to be shielded. The field intensity *(H)* is measured in Oersteds. Therefore:

$$g = H_o / H_{in}$$

where:

g = attenuation
H_o = field intensity outside, Oersteds
H_{in} = field intensity inside, Oersteds.

The shielding efficiency or shielding effectiveness *(SE)* is then expressed in decibels as:

$$SE = 20 log_{10} g$$

Therefore, the higher the H_o / H_{in} ratio, the higher the shielding effectiveness.

RFI shielding is effective because reflection is the primary shielding mode

Magnetic shielding is available in a range of high permeability levels and in varied thicknesses to match the flux density requirements of the application. For example, an 80 percent nickel shield (15 percent iron plus other) has a maximum permeability of 400,000 and is supplied in thickness increments ranging from 14- to 62-mils.

The behavior of nickel-iron when exposed to a magnetic field complicates the choice of the proper material and will influence shield design. For example, the material's permeability will increase with field density. Therefore, the attenuation will also increase as the magnetic field becomes stronger. However, as the shield reaches its maximum permeability, saturation occurs and permeability decreases. In addition, high permeability materials have lower saturation levels. Designing the proper shield requires the selection of a material with an adequate saturation level and with just high enough permeability to provide the necessary attenuation.

For strong magnetic fields, an effective design technique is to use multiple shields nested together as a single assembly. A number of thinner shields spaced by an air gap or by a non-magnetic material, such as aluminum, is more effective than a single, thick shield. This is because the first shield reduces the field strength acting on the next shield.

Companies specializing in supplying magnetic shielding materials and performing custom design include Amuneal, Philadelphia, Pa. and Perfection Mica, Bensenville, Ill. These companies have numerous charts and graphs to help in the selection and design of magnetic shielding.

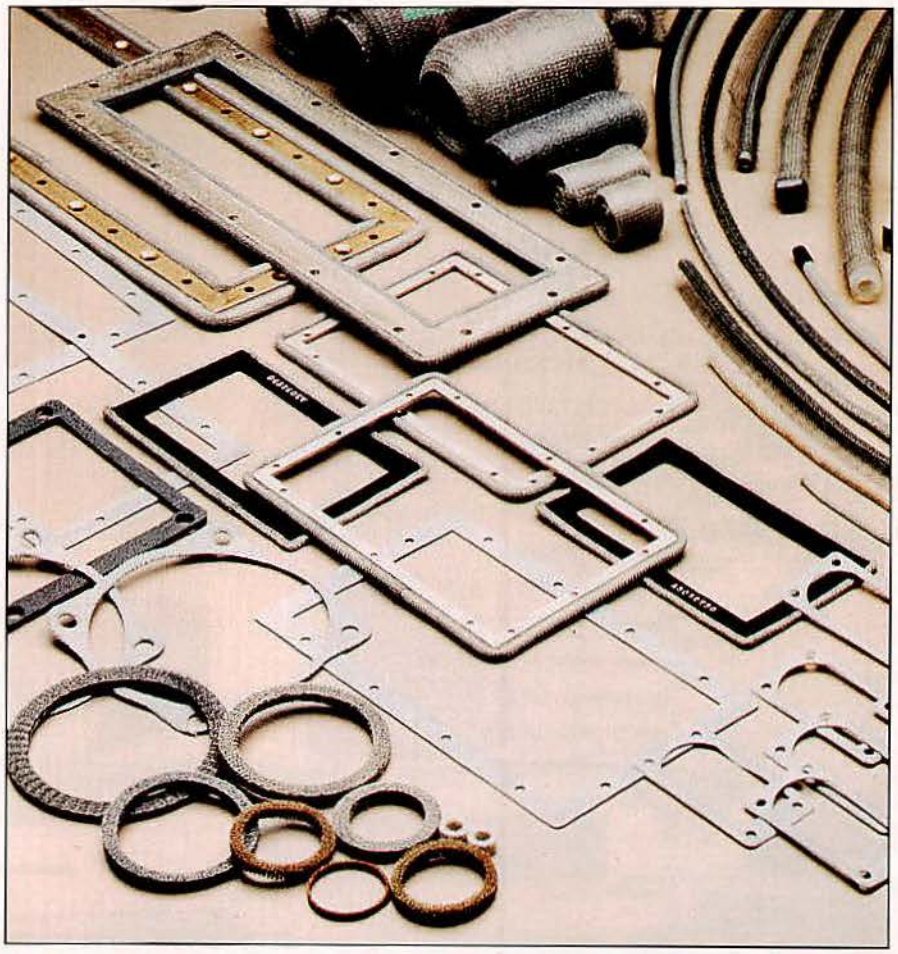


Figure 2. Knitted wire mesh *made in the form of gasketing can seal doors and covers against EMI/RFI leakage. (Chomerics)*

RFI shielding

Unlike magnetic shielding which relies mainly on absorption, RFI shielding is effective because reflection is the primary shielding mode. RF waves are of high impedance, whereas highly-conductive RFI shielding is of low impedance. This abrupt discontinuity in the wave's path causes most of the energy to reflect from the surface of the shield, while a smaller portion is absorbed.

The absorbed portion induces an electric current in the shield. The amount of current and the rate of current decay varies with the depth (thickness) of the shield and depends upon the shield's conductivity and permeability.

RFI shielding can be intended to either shield a cabinet or enclosure from incoming RF energy (receptor) or shield a cabinet or enclosure from emitting RF energy.

Preventing RFI emission requires that the shield also be an efficient energy absorber because the internal cabinet reflections will contain, but not totally dissipate, the RF energy. Therefore, shielding against RFI emission requires a shielding material having reasonable conductivity while also being permeable. This is why a nickel coating is often used as shielding inside plastic cabinets and also why steel enclosures are effective.

The shield must also be sufficiently thick so induced currents decay or weaken before reaching the external surface and radiating. In fact, shield thickness, in the case of absorption, plays the major role and is directly proportional to the shield's ability to attenuate the RF energy. For example, the absorption loss, A (in dB), provided by a metal shield is given by:

$$A = 3.338(10^{-3})t(\mu fG)^{1/2}$$

where:

t = shield thickness, mils

μ = relative permeability referred to free space

f = frequency, Hz

G = relative conductivity referred to copper.

Cabinets and enclosures containing receptors that must be shielded from incoming RF energy (electric field dominant) must be designed for maximum reflection. Therefore, high conductivity material such as copper is the most efficient shield. However, steel of sufficient thickness, such as that used for cabinets and enclosures, will provide effective shielding for most applications. The material's con-

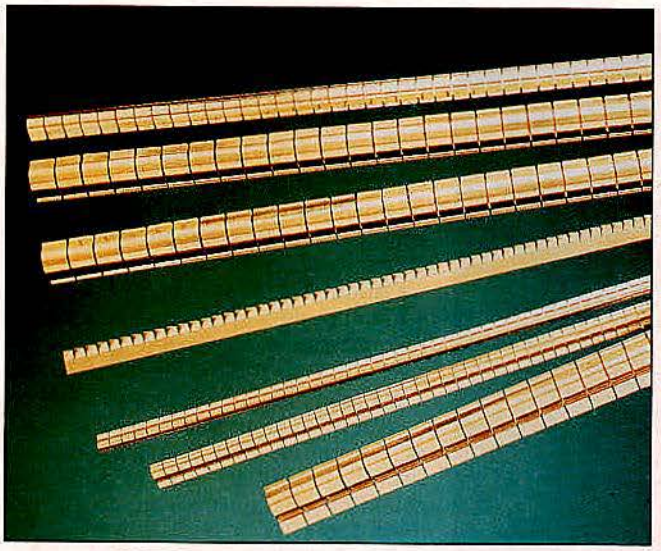


***Figure 3. Metal finger stock provides** a spring action against cabinet doors to ensure an EMI/RFI seal. (Instrument Specialties)*

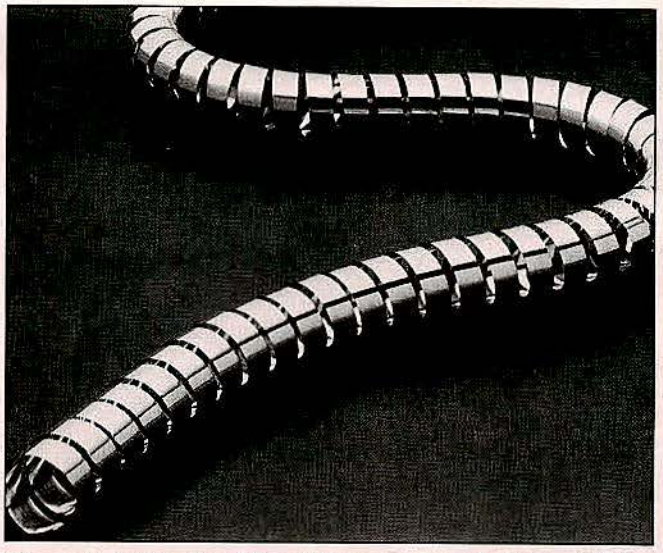


***Figure 4. A tin-plated beryllium copper spiral** is a highly resilient spring that seals against EMI/RFI. (Spira Manufacturing)*

ductivity plays the major role in attenuating RF energy. For example, the reflection factor, R (in dB), for an electric field dominated RF wave is given by:

$$R = 353.6 + 10log_{10}\frac{G}{f^3\mu r^2}$$

where:
r = distance from source to shield, in.

The overall shielding effectiveness, SE (in dB), of a given shield is the sum of the reflection *(R),* absorption *(A)* and a correction factor *(B)* that accounts for secondary reflections from the far side of the shield (internal to the material) back toward the front side. This reflection can either add or subtract from the primary or reflected wave depending on their phase relationship. The equation for shielding effectiveness is therefore:

$$SE = R + A + B$$

The factor B becomes insignificant when A is less than 6 dB. It is usually of importance when the shield is thin and at frequencies below 20 kHz.

Shielding material suppliers have generated charts, curves and nomographs to aid designers in establishing the relationships between reflection, absorption, secondary reflections, source-to-shield distance, shield material and thickness. These, together with the suppliers' experience, are a valuable resource for packaging engineers involved in EMI/RFI shielding problems.

Shielding effectiveness *(SE)* can be measured for specific cabinets and enclosures by placing an RF radiating source (antenna) outside and measuring the RF energy received inside. *SE* can be expressed either as a function of power density:

$$SE = 10log\frac{P_i}{P_e}$$

A critical aspect of shielding is ensuring the enclosure or cabinet is leakproof

where:
P_i = incident power density (before the shield)
P_e = exiting power density (after the shield);

or as a function of field strength:

$$SE = 20log\frac{F_i}{F_e}$$

where:
F_i = incident field strength
F_e = exiting field strength.

SE values measured when the RF source is placed inside the enclosure will vary from when the source is placed outside. This is due to internal reflections, enclosure resonance and antenna loading.

While EMI is difficult to totally eliminate, proper shielding design will sharply weaken its effects on electronic circuitry. EMI can be suppressed or shielded inside an electronics enclosure by protecting or isolating specific components. For example, transformers and CRTs can be covered with a magnetic shield for local suppression.

Eliminating EMI

Printed circuit boards can be protected by a clamshell shield construction that covers the entire assembly, except the connector. However, very often, shielding of individual devices will suffice. A solder-mounted thin metal box placed over a device is an effective shield. An alternate method involves using an EMI "fence" soldered to the board around the periphery of the device. A cover can then be soldered or snapped into place (Fig. 1).

One of the more critical aspects of shielding is ensuring that the metal enclosure or metal-coated plastic cabinet is leakproof. EMI/RFI can gain access or radiate from gaps and crevices around doors and covers. A number of companies, including Chomerics, Woburn, Mass.; Instrument Specialties, Delaware Water Gap, Pa.; and Spira Manufacturing, N. Hollywood, Calif., offer EMI gasketing products designed to prevent leakage.

These products include gaskets made from knitted wire mesh (Fig. 2), conductive elastomer, metal finger stock (Fig. 3) and gaskets designed as

Dirt and corrosion can decrease shielding effectiveness

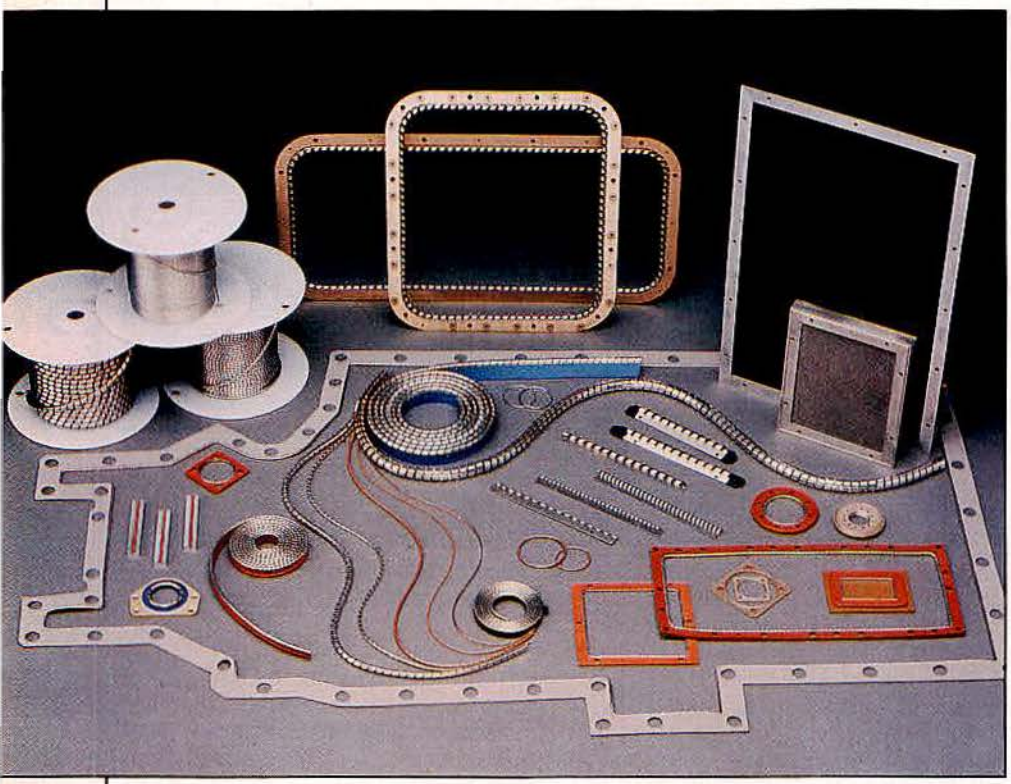


***Figure 5. The spiral in Fig. 4 can be used alone** or in combination with other gasket materials to form varied designs. (Spira Manufacturing)*

Defining Electromagnetic Radiation

All electromagnetic waves consist of two components: a magnetic field and an electric field. The relative magnitude between the magnetic (H) field and the electric (E) field depends on how far away the wave is from its source, and on the nature of the generating source. The ratio of E to H is called the wave impedance.

If the source has a large current flow compared to its voltage, such as that which may be generated by a transformer or power lines, it is called a current, magnetic or low impedance source. The latter is true because the ratio of E to H has a small value.

Conversely, if the source operates at high voltage and only a small amount of current flows, the source impedance is said to be high, and the wave is referred to as an electric field.

At very large distances from the source, the ratio of E to H is equal regardless of the type of source. When this occurs, the wave is said to be a plane wave, and the impedance is equal to 377 ohms (the impedance of free space).

The importance of wave impedance can be illustrated by considering what happens when an electromagnetic wave encounters a discontinuity such as a metal shield. If the magnitude of the wave impedance is greatly different from the intrinsic impedance of the shield, most of the energy will be reflected and very little will be transmitted across the boundary and absorbed.

Metals have an intrinsically low impedance because of their high conductivity. Therefore, for low impedance waves (H dominant), less energy is reflected and more is absorbed because the metal shield is more closely matched to the impedance of the wave.

a metal spiral (Fig. 4).

Knitted wire mesh gaskets are formed from various metals including nickel-copper alloy and tin-plated, copper-clad steel. Knitted gaskets offer durability, resilience and corrosion resistance. They are recommended for applications that do not require shielding effectiveness levels above 90 dB at over 1 GHz.

Conductive elastomer EMI gaskets are composites of silicone or fluorosilicone with a dispersion of conductive filler particles, usually silver. They offer the benefit of providing an environmental pressure seal as well as preventing EMI leakage. Conductive elastomers are said to provide a shielding effectiveness of up to 120 dB at 100 MHz.

Metal finger stock is made from spring materials like phosphor bronze and beryllium copper. It offers a shielding effectiveness of over 100 dB.

The metal spiral is comprised of a tin-plated beryllium copper ribbon wound into a highly resilient spring. It is claimed to provide a shielding effectiveness as high as 140 dB. The spiral shield can be used as a gasket by itself or be combined with other gasket materials for additional design versatility (Fig. 5).

EMI/RFI gaskets will perform effectively only if they are in continuous electrical contact with the surfaces of the enclosure. Dirt and corrosion will cause a decrease in the shielding effectiveness. Suppliers recommend that metal mating surfaces be cleaned at regular intervals by first wiping with a clean cloth soaked in ethyl alcohol and then spraying with a solvent such as an electronic tuner cleaner. While the enclosure itself may offer the required EMI/RFI shielding, faulty gasketing will cause the system to fail EMC tests. **EP&P**

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